

Materials  
Research  
Laboratory,  
Inc.



22333 Governors Highway ♦ Richton Park Illinois ♦ 60471  
Pilgrim 8-8777 ♦ Chicago telephone ♦ Pullman 5-4020

## FINAL REPORT

on

### ELEVATED TEMPERATURE STRESS CORROSION OF HIGH STRENGTH SHEET MATERIALS IN THE PRESENCE OF STRESS CONCENTRATORS

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R. G. Lingwall and E. J. Ripling

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**MECHANISM OF HOT SALT STRESS  
CORROSION CRACKING OF TITANIUM BASE ALLOYS**

by

**R. G. Lingwall and E. J. Ripling**



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## ABSTRACT

Experiments on the electrochemical aspects of hot salt cracking of titanium alloys suggest that cracking occurs due to the formation of an oxygen differential cell. Cracking occurs only at the cathode of the cell, and can be prevented by impressing an anodic potential on the stressed titanium.

Hydrogen produced at the cathode where it enters the metal is deduced to be the basic cracking agent.



## INTRODUCTION

Because titanium base alloys have an excellent strength to weight ratio with a high fracture toughness in the temperature range of 400-800° F, they are among the most promising structural materials for use in this temperature range. This promise, however, is clouded by the susceptibility of the alloys to stress corrosion cracking in the presence of hot solid salt. Although cracking occurs readily in laboratory testing, and is reasonably reproducible, to date no service failures have been attributed to hot salt (1). Brittle cracking at low loads, however, is a potential danger with each new application. Ascertaining the service conditions under which embrittlement may be expected as well as the eventual elimination of the problem requires a better understanding of the mechanism of cracking.

Although there was an awareness of this susceptibility as early as 1957, studies of the mechanism are relatively rare. The first published report on the subject (2) implied that cracking was caused by a gaseous reaction product produced by general corrosion, e. g. chlorine or hydrogen chloride, which attacked the grain boundaries. This was a particularly attractive mechanism since it would explain the difference between laboratory behaviors, in which the corrosion products are trapped in a stagnant atmosphere, and service conditions in which gaseous reaction products are washed away by a fast moving air stream.

Crosley, et al, were the first to dispute the "gaseous attack" mechanism (3). They suggested that the protective  $\text{TiO}_2$  was first dissolved by the chloride salt, after which the titanium and salt could react to form a mixture of titanium chlorides. The latter would depress the melting point of the salt layer adjacent to the metal to form a liquid that could presumably follow the advancing crack. Nevertheless the suggested mechanism involving attack by a gaseous corrosion product persisted and was given as a possible cause for the absence of service failures in a 1965 symposium (4) by Petersen and Bomberger (5) and by Hatch, et al (6). At the same meeting, Kirchner and Ripling showed that cracking was not caused by a gaseous corrosion, at least in Ti-8Al-1Mo-1V, and attributed it to either a lowering of the surface energy by a solid corrosion product or else to hydrogen embrittlement (7). Rideout, Louthan and Selby found by radioactive tracer studies that  $^{36}\text{Cl}_2$  and  $\text{H}_2$  were fairly uniformly distributed throughout the circular areas initially wetted by the salt solution (8) after high temperature exposure. On the basis of this, they also concluded that the cracking might be caused by hydrogen embrittlement.



The experimental results necessary to unequivocally support one or the other of the proposed cracking mechanisms was lacking. Consequently, the series of studies discussed in this report were undertaken. These were directed primarily toward contributing to an understanding of the electro-chemical aspects of the problem, and to ascertain whether or not hot salt cracking was a manifestation of hydrogen embrittlement. The studies are described in a logical sequence with each experiment suggesting the one that follows.

## M A T E R I A L S

The titanium alloy, Ti-8Al-1Mo-1V was used throughout this study. It was supplied as 0.018 inch thick sheet in the mill annealed condition, so that it was probably free of residual stresses. The corroding medium was sea salt. The latter was made by evaporating natural sea water to the consistency of a thick paste. The slurry was applied to the specimens, either as small beads or as a thick coating.

## T E S T   R E S U L T S

### Salt Drop Experiments

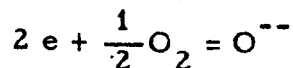
One unique aspect of the stress corrosion cracking of these alloys is its apparent insensitivity to initial stress concentrators. When sharply notched specimens, with the dimensions shown in Fig. 1a, were heavily salt coated in the vicinity of the notch, as shown schematically in Fig. 1b, and exposed at 650°F to a nominal stress of 25,000 psi (calculated on the basis of the notch section area), they cracked at the edge of the salt layer, Fig. 1c, rather than across the notch plane where the stress is far higher due to both the reduced cross-section and the stress concentration (9). Since the specimens crack at the location of lower stress, it might be assumed that cracking is independent of applied stress. This is shown not to be the case, however, by the smooth tensile specimen exposure data in Fig. 2. Hence it must be assumed that stress corrosion cracks can form only at the edge of the salt layer, and the load carrying capacity at this location is reduced far more than is the strength reduction produced by the mechanical notch.



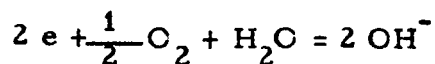
Kirchner and Ripling showed this strength reduction to be associated with a gray corrosion product that formed at the periphery of heavy salt layers. Cracks always initiated near this location, Fig. 3. The fact that cracking is restricted to this single site suggests that the fracture is associated with an electro-chemical mechanism in which the metal near the salt-metal-air interface is always one electrode of the cell. Determining whether the periphery is the anode or cathode of the cell can be done by examining the metal after it has been in contact with a drop of the corroding agent. At the anode, metal is dissolved, i. e.,



while at the cathode, oxygen is reduced,



or



Hence, small beads of a slurry of natural sea salt were placed on metallographically polished surfaces of Ti-8Al-1Mo-1V alloy and heated to 800°F for five hours in the absence of stress. After the high temperature exposure, the salt and corrosion products were carefully washed off, and the metal in the vicinity of the original salt bead had the appearance shown in Fig. 4. Under the center section of the bead, where air was excluded, the metal was dissolved indicating an anodic reaction. At the periphery of the salt bead the oxide appears to have been removed implying a cathodic reaction. The appearance of the pit in relation to the original salt bead is more clearly seen in Fig. 5. Note that in short exposure times, metal is dissolved only under the center of the bead where oxygen is least available. This appearance would suggest that titanium alloys, in the presence of hot solid salt, corrode because of an oxygen differential cell, much as is the case for a salt water drop on steel (2). The metal under the thickest part of the salt bead, i. e., its center, is deficient in oxygen as compared with that near the periphery.

#### Oxygen Differential Corrosion Cell

To be certain that corrosion was the result of an oxygen differential, tests were also carried out in a cell in which one piece of stressed titanium was maintained in a vacuum or argon atmosphere while a second



piece of titanium, exposed to the air, was in contact with the first one through a salt bridge and also connected to it electrically by a nickel wire. A schematic diagram of the cell is shown in Fig. 6, and the details of its construction have been previously described (9). When the system was heated to the vicinity of 650 to 800<sup>o</sup>F, an emf varying from 1.0 to 0.1 volts was measured and the direction of current flow showed that the inside oxygen deficient specimen was the anode and the outside the cathode.

#### Effect of an Impressed emf

Since cracking appears to be identified with the cathodic region, it should be possible to prevent failures by making the stressed member the anode in a titanium-salt-titanium cell. In order to do this, a small hole was drilled into the reduced section of tensile specimens, Fig. 7a. After drilling, the specimen was cleaned in acetone and then in Alconox. One side of the specimen was then coated with a thick salt slurry, and a small metal tab of the same alloy (Ti-8Al-1Mo-1V), Fig. 7b, placed over the salt, and the assembly held together with a single steel screw and nut, Fig. 7c. The fastener was insulated from the titanium surfaces by a small sheet of mica under the head of the screw and a sheet of mica and ceramic bead under the nut. The screw was prevented from touching the sides of the hole by making the hole considerably larger than the screw diameter.

Four groups of specimens of this type were tested by exposing them at 650<sup>o</sup>F to 50,000 psi stress (calculated on the basis of the cross-sectional area containing the hole diameter). The specimens were tested in a creep furnace, the ends of which were plugged with an insulating material so that the atmosphere within the furnace was stagnant. An emf of either 25 or two volts was supplied between the specimen and attached electrode.

In the first group, consisting of six tests, the specimen was made the cathode of a 25 volt cell, Fig. 8a, and as shown in Table I, fractures occurred in times between 26 and 180 hours. The second group of five specimens was tested to serve as controls, Fig. 8b, in which no voltage was applied, and these failed between 2 and 155 hours. Note that most of these control specimens did not fracture at the edge of the salt layer. This resulted because air could travel through the



hole to the salt coated side of the specimen since they were not coated on the back side. Hence, cathodes would be expected to form both near the edge of the salt layer and the periphery of the hole. In a third series, eight stressed specimens were made the anode, Fig. 8c, and although one failed in fourteen hours, the remainder of the specimens did not fail within the total test period which varied from 225 to 864 hours. Since currents were not measured during the test, it is probable that poor contact was made between the specimen, salt and electrode in the single test in which premature fracture occurred. In the final test series, six specimens were again made the anode but in this case, an impressed emf of 2.0 volts was used. As shown in Table I, none of these six failed within the 300 hour test period.

### Hydrogen Embrittlement Tests

The fact that embrittlement occurred at the cathode of the cell, and indeed could be prevented by making the stressed test specimen an impressed anode, suggested that cracking was not stress corrosion cracking in the more classical sense, but was caused by adsorbed hydrogen. Attempts to find differences in the hydrogen level of salt exposed and unexposed specimens by the use of vacuum fusion techniques were unsuccessful, however. Since this might have resulted because of an insufficient sensitivity of the method, radioactive tracer techniques were also tried. Both sodium chloride and sea-salt slurries were made using tritiated water. Small beads of the slurries were placed on sheets of titanium, and these were heated to 700<sup>o</sup>F, for 4, 16 and 20 hours, in an unstressed condition. The specimens were then rinsed and lightly polished to be sure that all the surface corrosion products were removed. Although both photographic film and counting techniques indicated the probable presence of some hydrogen, the results could not be considered unequivocal.

Because of this difficulty of detecting hydrogen directly, an indirect mechanical method was used. If hydrogen enters the metal when elevated temperature corrosion occurs, a salt coated titanium specimen held at the embrittling temperature in the absence of stress should exhibit hydrogen cracking in subsequent room temperature tests. To determine whether or not this were the case, double edge notched sheet tensile specimens (see Fig. 1a) were used since a considerable amount of experience had been gained on their use in the course of this project.



To avoid the ambiguity encountered by Kirchner and Ripling who were not able to determine whether cracking was caused by a corrosion product which diffused over the surface or by hydrogen which was diffusing within the metal at roughly the same rate (7) it was necessary that cracking occur in a portion of metal which had not been coated with the corrosion products. Since both the surface corrosion products and hydrogen appear to diffuse outward from the salt bead, it is necessary for the hydrogen to lead the corrosion products if cracking is to occur in "clean" metal. This would require that the diffusion rate of the hydrogen ions be greater than that of the surface corrosion products, or else that the hydrogen be generated at the corrosion product-metal-air interface. Either of these would cause cracking to occur ahead of the advancing surface corrosion products.

To determine whether or not such cracking could occur, specimens were coated with a narrow salt bead on either side of the notch, on both sides of the specimen, as shown in Fig. 9. These, as well as a single uncoated specimen, used as a control, were then placed into a tube furnace and heated to 800<sup>o</sup>F (one to two hours was required to reach temperature) held 7, 8 or 24 hours after which they were air cooled to room temperature. The salt and corrosion products were then washed off with distilled water. (The specimens exposed for 24 hours were also metallographically polished in the vicinity of the notch plane to be certain that even water insoluble corrosion products were removed.) The cleaned specimens were then subjected to 100,000 psi (net section stress) at room temperature.

In spite of the fact that these specimens were thoroughly cleaned after high temperature salt exposure, corrosion times and temperatures were selected such that none of the surface corrosion product would diffuse to the notch plane. (Note the limits of the dark corrosion product at the periphery of the salt beads in Fig. 9.)

As shown in Table II, the control specimen did not fracture within the period of the subsequent room temperature test. The coated specimen given the shortest exposure developed a small crack while the remainder fractured completely in very short times. In all cases, cracking occurred across the notch plane, Fig. 10, unlike the condition shown in Fig. 1, where cracking was restricted to the edge of the heavy



salt layer. These results imply that hydrogen is being absorbed at the cathode and it is the hydrogen ions rather than the surface corrosion products that cause titanium to be embrittled in the presence of hot salt.

To be certain that cracking was indeed caused by hydrogen, a systematic study of the influence of salt exposure on room temperature stress vs time-to-fracture was carried out. In all the following tests, the notch radius was increased to two mils from the less than one mil used in the tests described above.

The first three series of tests were carried out on as-received, i. e. mill annealed, titanium. The specimens in one of the three series were used as a control, and those for the other two were thoroughly cleaned and ground with 400 grit emery paper. Salt beads were placed on the latter specimens as described above and these were then exposed 24 hours in the absence of stress at 800<sup>0</sup>F. At the completion of the exposure, the specimens were again cleaned of all salt and corrosion products after which both the exposed and control specimens were subjected to a constant load at room temperature.

The high temperature exposure dates for these two series were selected so that room temperature humidity was 40 to 60 percent for one series, and 10 to 20 percent for the other. As shown in Fig. 11, delayed failure occurred at stress levels between 92 and 95,000 psi for the higher humidity exposure while for the lower humidity, failures did not occur below 100,000 psi. Indeed the specimens exposed at the lower humidity appeared to be no more embrittled than the control specimens. This need for some reasonably high humidity to cause hot salt cracking is consistent with the earlier Kirchner and Ripling finding (7).

Because there was a considerable time dependence for room temperature fracture of the control specimens, the mill annealed material could not serve satisfactorily for base-line comparisons. For example, if one assumed that hydrogen caused the cracking, delayed failure on subsequent room temperature exposure should be eliminated by inserting a vacuum annealing process between the elevated temperature salt exposure, and the subsequent room temperature stressing. To be certain that the inserted vacuum annealing did not change the



delayed failure characteristics of the metal, it would be necessary to stabilize the specimens by means of a vacuum anneal prior to the salt exposure. As shown in Fig. 12, the stabilizing anneal ( $1300-1325^{\circ}\text{F}$  at  $5 \times 10^{-5}$  mm Hg for 24 hours) did so significantly improve the metal's resistance to delayed fracture that this treatment was used on all subsequent tests.

To re-evaluate the effect of water vapor during salt exposure on stabilized specimens, two more groups of specimens were treated as follows:

1. Specimens cleaned and ground on notch plane with 400 grit emery paper.
2. Vacuum stabilize  $1300-1325^{\circ}\text{F}$  at  $5 \times 10^{-5}$  mm Hg for 24 hours.
3. Bands of salt slurry placed on the specimens near the notch plane. To be certain that this operation was reproducible, four lines were scribed on each side of the specimen; the first pair of lines 0.1 inch away from the notch plane, and the second pair, 0.1 inch away from the first ones. Each set of lines, 0.1 inches apart, described an area in which the salt was to be placed. The salt slurries were weighed out ( $0.1 \pm 0.005$  gms) and placed on the specimens on each side of the notch on both sides of the specimen.
4. The unstressed specimens were placed on a rack so that the salt beads were vertical, and the rack placed in the furnace at room temperature. The furnace power was adjusted so that the desired temperature was reached in two hours.
  - a. One series was exposed at  $800^{\circ}\text{F}$  for 24 hours at ambient humidity.
  - b. The second series was exposed 24 hours at ambient humidity plus 24 hours with water dripping into the furnace to produce a high humidity. This exposure was selected on the basis of corrosion product appearance. In the "dry" atmosphere, a black product is



formed which turns light in color on subsequent contact with moisture (see photographs in ref. 7). If the "wet" atmosphere is used at the beginning of the exposure, the reaction of the water and salt is so violent that the salt beads are blown off.

5. Clean specimens of salt and corrosion products.
6. Expose to stress at room temperature.

As was found with the mill annealed specimens, the higher humidity caused a much more severe embrittlement, Fig. 13.

Since the dry plus wet exposure causes such a pronounced embrittlement, this treatment was used to investigate the effect of exposure temperature. Specimens were treated by steps 1 to 5 above, except in 4a, temperatures between 650 and 900<sup>o</sup>F were used. As shown in Fig. 14, the higher the exposure temperature, the more severe the embrittlement.

To be certain that the embrittlement required salt and was not due simply to hydrogen pick-up from the steam, another series was conducted in which all the above steps were used except no salt was applied in step 3; the exposure temperature was 900<sup>o</sup>F. The subsequent room temperature stress-time curve for this material was identical with the specimens subjected to vacuum stabilization only, Fig. 15.

These test results would indicate that hot salt stress corrosion cracking is indeed a manifestation of hydrogen embrittlement. If this is the case, the embrittlement should be eliminated by inserting a vacuum annealing treatment between the elevated temperature salt exposure and the room temperature stress exposure. To ascertain whether or not this were the case, specimens were salt exposed exactly like the 900<sup>o</sup>F specimens in Fig. 14. The vacuum stabilizing treatment inserted prior to room temperature stressing was also identical with that done prior to salt exposure except that some of the specimens were annealed 24 hours and others 48 hours. As shown in Fig. 16, the inserted anneal did indeed result in a recovery of properties supporting the thesis that embrittlement is caused by absorbed hydrogen.



## DISCUSSION AND CONCLUSIONS

The studies described above suggest that hot salt cracking of titanium alloys is associated with the electrochemical corrosion that occurs due to the formation of an oxygen differential cell; the periphery (salt-air-metal interface) being the cathode and the center of the salt bead being the anode. As such it is analogous to the case of a salt water drop on iron.

Cracking occurs only at the cathode and can be prevented by impressing an anodic potential on the stressed titanium. In this sense, it is different from the recognized behavior of stress corrosion cracking processes where cathodic protection is required.

Hydrogen produced at the cathode and entering the metal is deduced to be the basic cracking agent. Since hydrogen could not be detected by vacuum fusion or radioactive tracer techniques, its existence and role had to be inferred from mechanical and thermal behavior.

Salt exposed specimens (high temperature, no stress) display delayed failure at room temperature under stress which is typical of hydrogen embrittlement. More significantly, the delayed failure tendency persists at room temperature when the salt and corrosion products have been removed. Finally, the propensity for room temperature delayed failure can be reduced or eliminated by interposing a vacuum anneal on the cleaned specimens between the salt exposure stage and the static load testing at room temperature.

In this case, hydrogen embrittlement and stress corrosion cracking as presently understood are distinguishable because it is well known that stress corrosion cracking can neither initiate or propagate when the embrittling environment has been removed.



TABLE I

RESULTS OF INDUCED ANODE, INDUCED CATHODE

AND CONTROL EXPERIMENTS

ALL SPECIMENS WERE EXPOSED AT 650°F

AND STRESSED TO 50,000 psi

Impressed Cathodes

<u>Time, hrs.</u>	<u>D. C. Voltage</u>	<u>Failed</u>	<u>Did not fail</u>
26	25	X	
34	25	X	
79	25	X	
83	25	X	
121	1.5	X	
180	25	X	

Controls

<u>Time, hrs.</u>	<u>D. C. Voltage</u>	<u>Failed</u>	<u>Did not fail</u>
2	0	X	
86	0	X	
90	0	X	
131	0	X	
155	0	X	

Impressed Anodes

<u>Time, hrs.</u>	<u>D. C. Voltage</u>	<u>Failed</u>	<u>Did not fail</u>
14	25	X	
225	25		X
225	25		X
252	25		X
252	25		X
647	25		X
864	25		X
864	25		X
303	2.0		X
303	2.0		X
306	2.0		X
307	2.0		X
308	2.0		X
309	2.0		X



TABLE II

INFLUENCE OF NO-LOAD EXPOSURE AT 800°F  
ON TIME-TO-FRACTURE IN SUBSEQUENT ROOM  
TEMPERATURE TEST WITH 100,000 psi (NET SECTION STRESS)

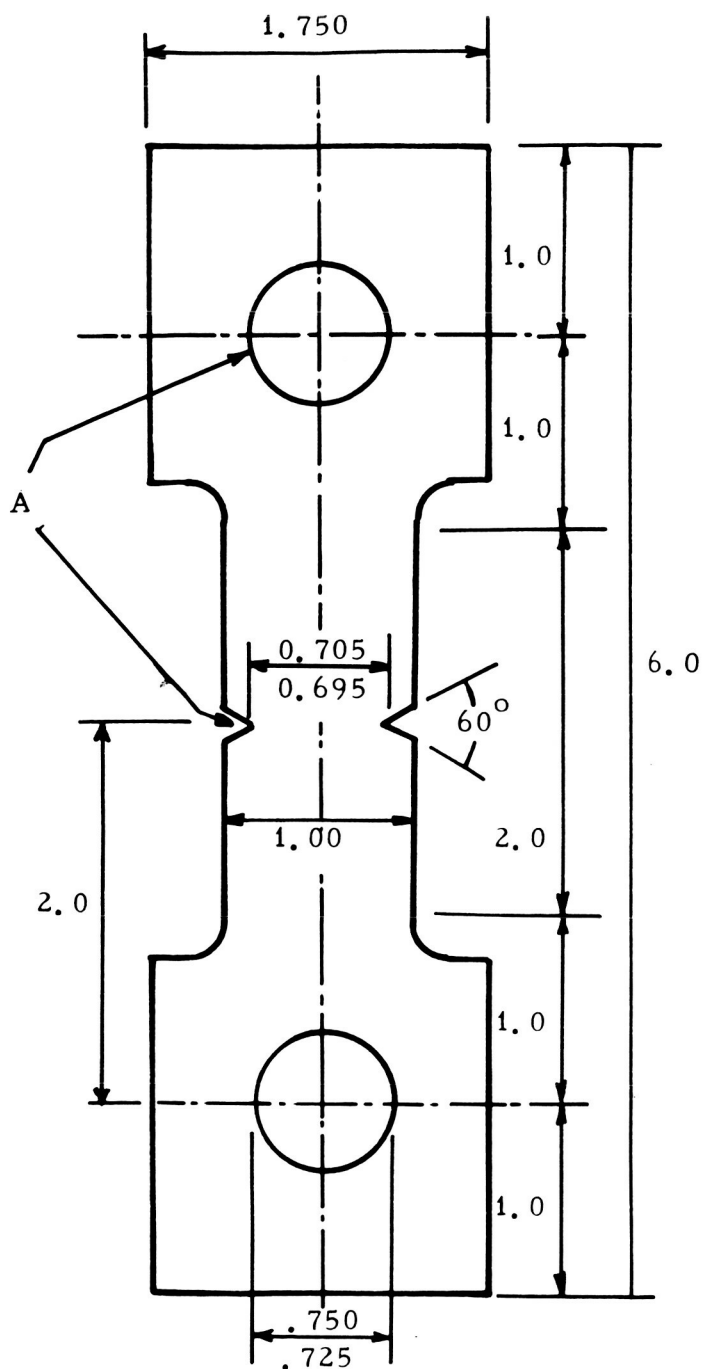
<u>Exposure Condition</u>	<u>Exposure Time Hours</u>	<u>Time to Fracture in Subsequent R. T. Exposure</u>
Air	24.5	Did not fail in 790 hours
Salt Near Notch	7	1/16 inch crack extended from each notch in 5 minutes. No additional extension in 20 hours.
Salt Near Notch	8	0.7 hours
Salt Near Notch	24 *	< 1 minute
Salt Near Notch	24 *	< 1 minute

\* Specimen surface metallographically polished in vicinity of notch to insure removal of corrosion products after high temperature exposure and prior to room temperature exposure.



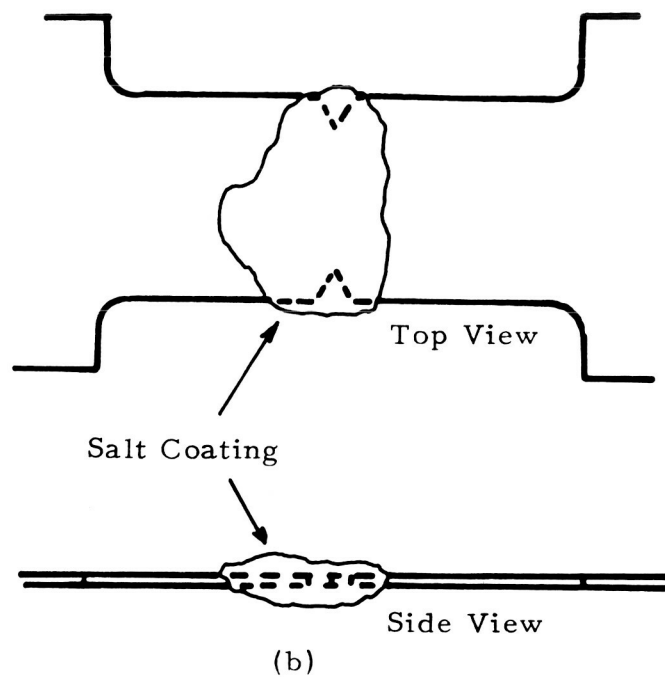
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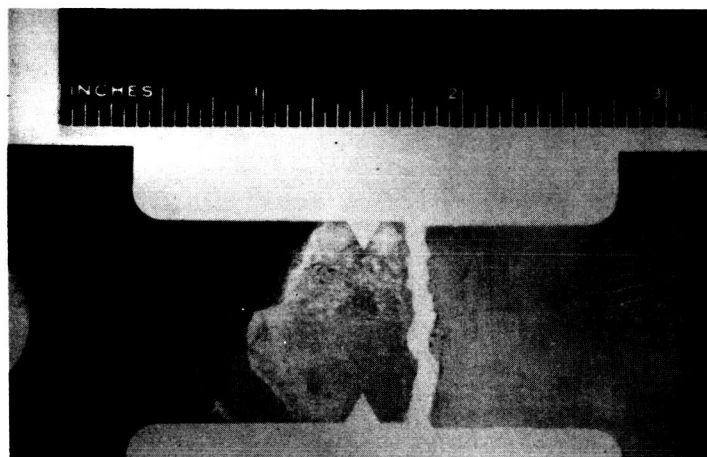


A - Surfaces true to centerline within  
0.001 inch. Notch root radius  
less than 0.001 inch.

(a)



(b)



(c)

Fig. 1 CRACKING IN A HEAVILY COATED EDGE NOTCH SPECIMEN

(a) SPECIMEN DIMENSIONS

(b) METHOD OF SALT COATING

(c) APPEARANCE OF FRACTURED SPECIMEN (Ti-8Al-1Mo-1V)

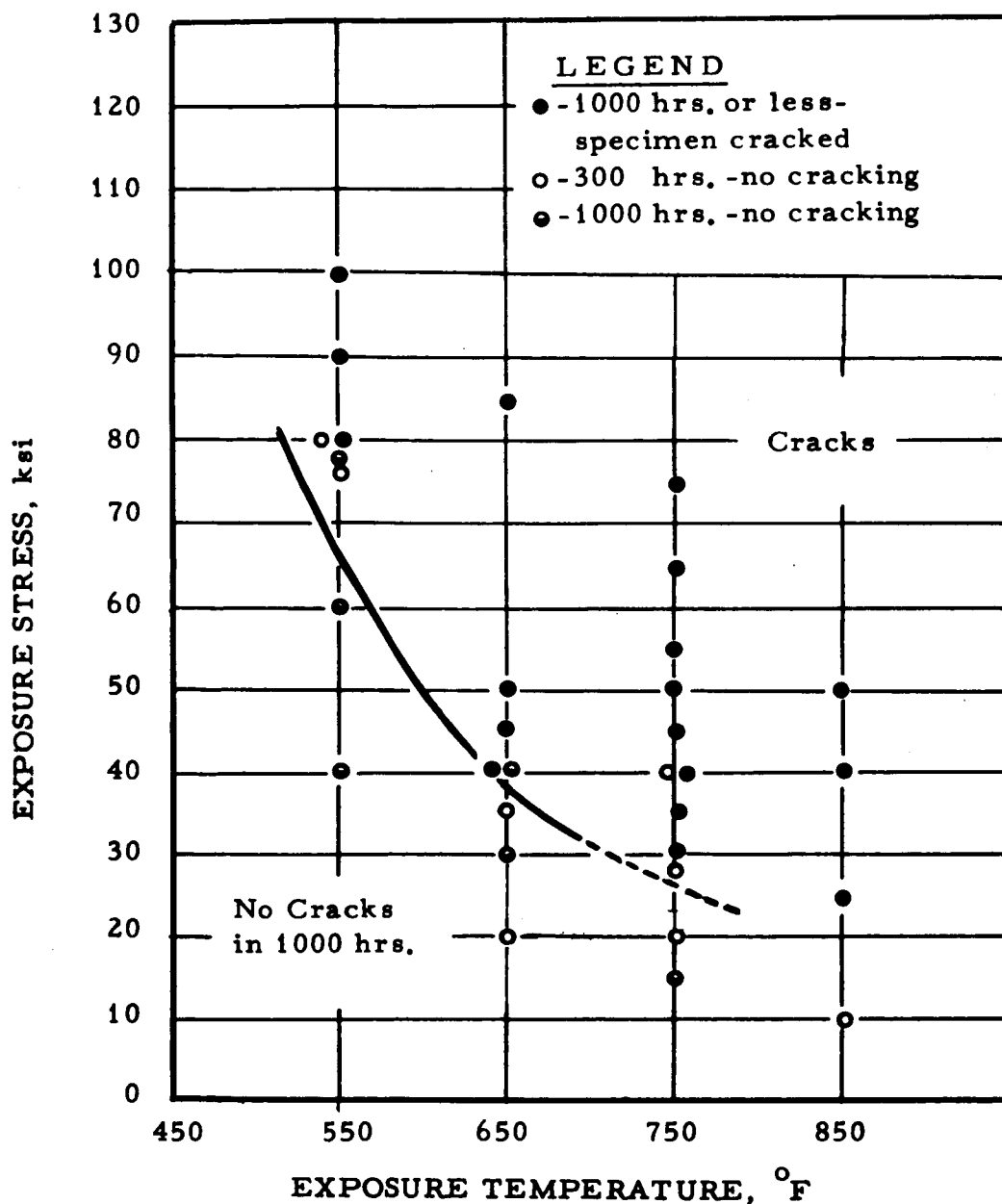


Fig. 2 EFFECT OF EXPOSURE STRESS AND TEMPERATURE ON FRACTURE OF ANNEALED Ti-6Al-4V ALLOY IN THE PRESENCE OF NaCl

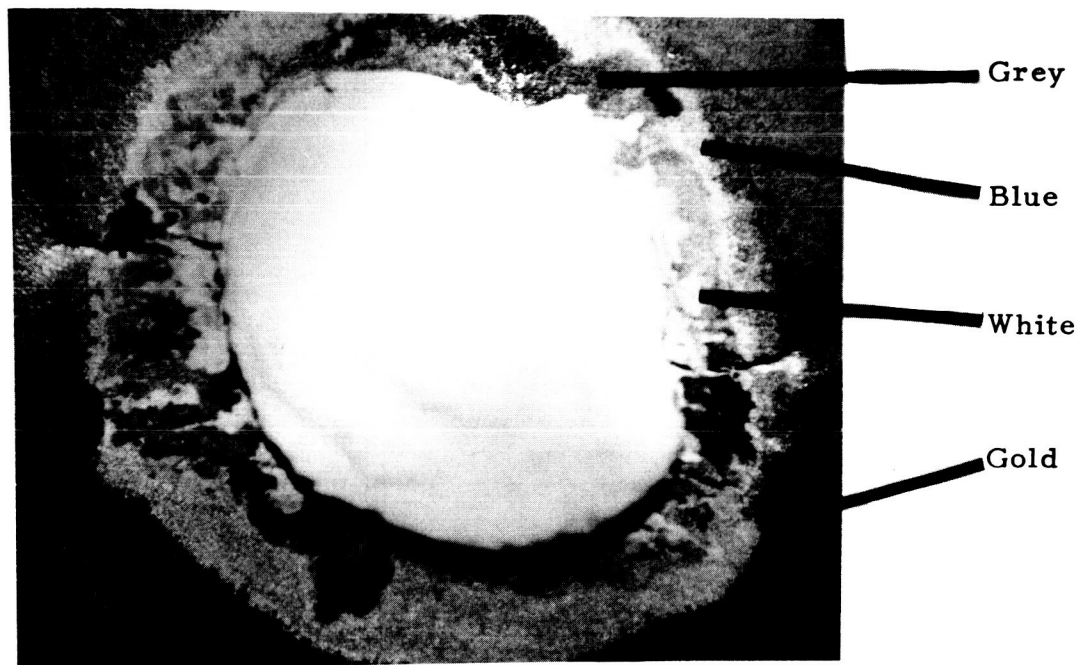


Fig. 3 CRACKING IN THE VICINITY OF THE SOLID BEAD (Ti-8Al-1Mo-1V, EXPOSED 25 HOURS AT 650°F and 70,000 psi. SPECIMEN ETCHED BEFORE APPLYING SEA SALT SLURRY.) (25x)

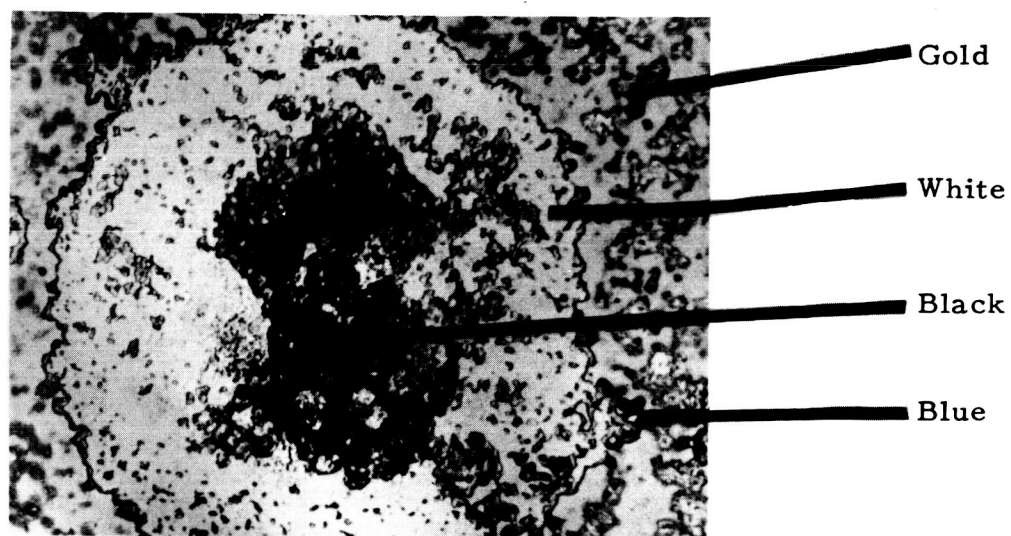
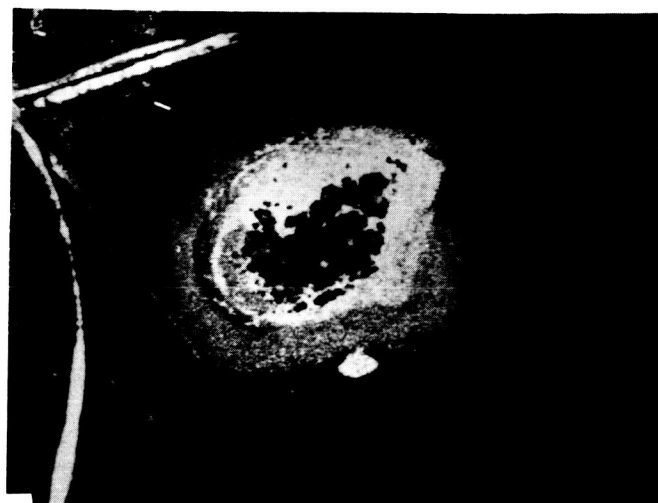


Fig. 4 APPEARANCE OF CORROSION PIT IN UNSTRESSED Ti-8Al-1Mo-1V SPECIMEN AFTER 5 HOURS AT 800°F (260x)



(a)



(b)



(c)

Straw Yellow

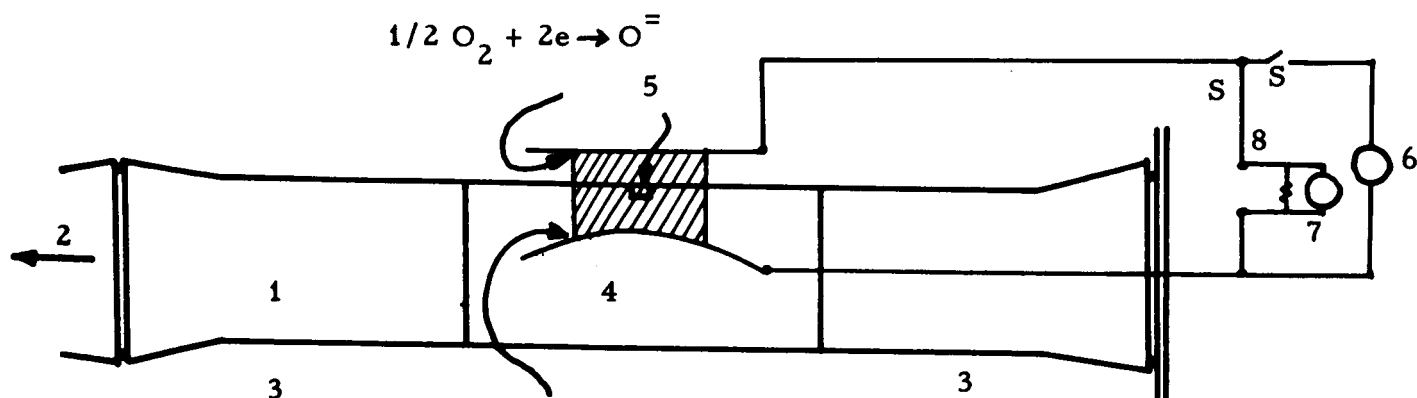
Blue

Black

White

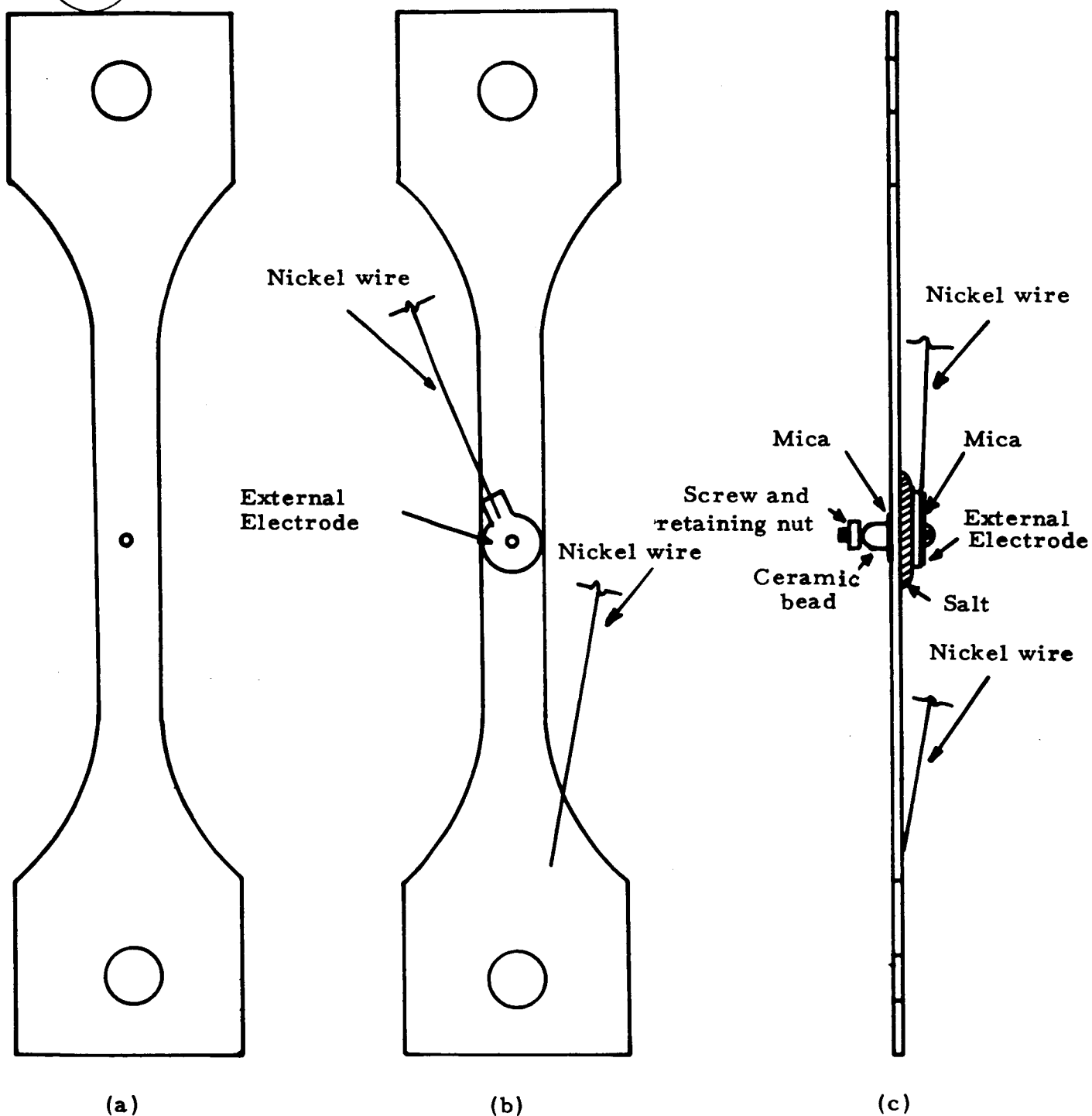
Fig. 5 SURFACE ATTACK OF SEA SALT ON UNSTRESSED Ti-8Al-1Mo-1V SPECIMEN

- (a) APPEARANCE OF SALT BEAD AND CORROSION PRODUCTS AFTER BEING EXPOSED AT 800°F FOR 5 HOURS (25x)
- (b) SURFACE ATTACK AFTER REMOVAL OF SALT AND CORROSION PRODUCTS (25x)
- (c) ENLARGED VIEW OF ATTACKED AREA (50x).



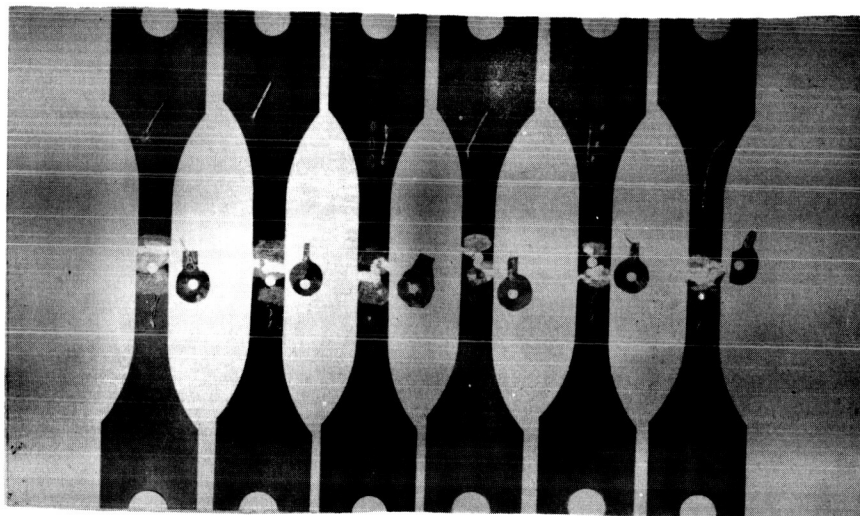
**Fig. 6** SCHEMATIC DIAGRAM OF CONTROLLED ATMOSPHERE CORROSION CELL.

1. Vacuum or argon chamber
2. To vacuum or argon
3. Glass ends of 4 inch diameter tube
4. Glazed alumina tube sealed to glass  
(glazed to prevent porosity)
5. Unglazed area on tube permeated with salt
6. Vacuum tube voltmeter
7. L and N mv. recorder
8. Precision resistor

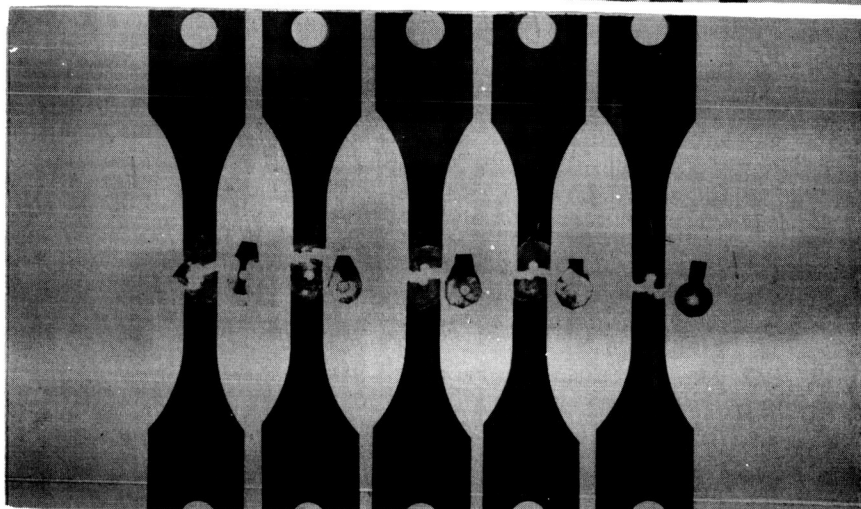


**Fig. 7** DIAGRAM OF THE IMPRESSED ANODE AND CATHODE SPECIMENS.

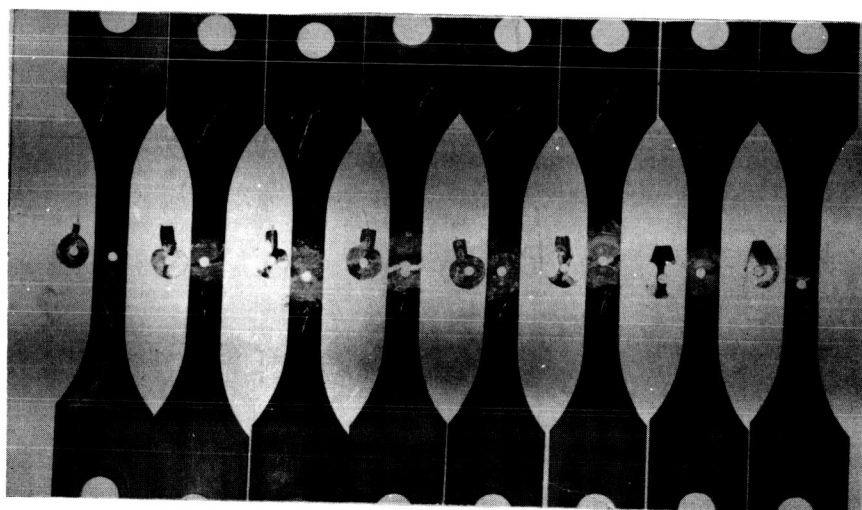
- (a) TENSILE SPECIMEN WITH HOLE.
- (b) TENSILE SPECIMEN WITH EXTERNAL ELECTRODE AND WIRES ATTACHED.
- (c) SIDE VIEW OF THE TENSILE SPECIMEN SHOWING THE DETAILED CONSTRUCTION OF THE TITANIUM-SALT-TITANIUM CELL.



(a)



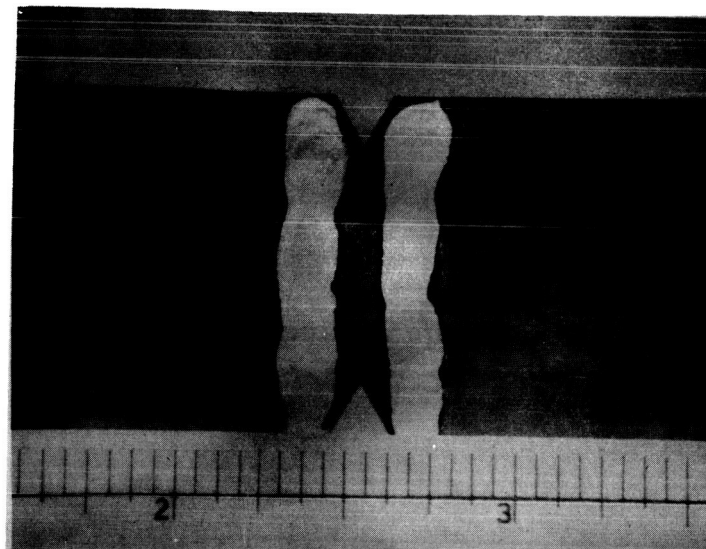
(b)



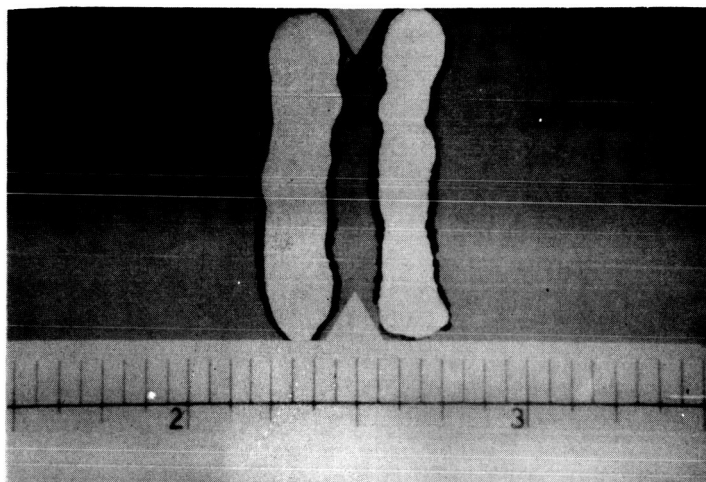
(c)

Fig. 8 APPEARANCE OF IMPRESSED EMF SPECIMENS AFTER TESTING:

- (a) IMPRESSED CATHODE SPECIMENS AFTER EXPOSURE TO 650°F AND 50,000 psi UNTIL FAILURE
- (b) CONTROL SPECIMENS AFTER EXPOSURE TO 650°F AND 50,000 psi UNTIL FAILURE
- (c) IMPRESSED ANODE SPECIMENS AFTER EXPOSURE TO 650°F AND 50,000 psi UNTIL TEST WAS STOPPED



(a) Front side



(b) Back side

Fig. 9 LOCATION OF SALT BEADS AND SURFACE APPEARANCE OF Ti-8Al-1Mo-1V NOTCH SPECIMEN AFTER EXPOSURE AT 800°F FOR 24 HOURS WITH NO LOAD. Note that corrosion products (dark stain at periphery of salt bead) did not extend to notch plane. (1.75 X)

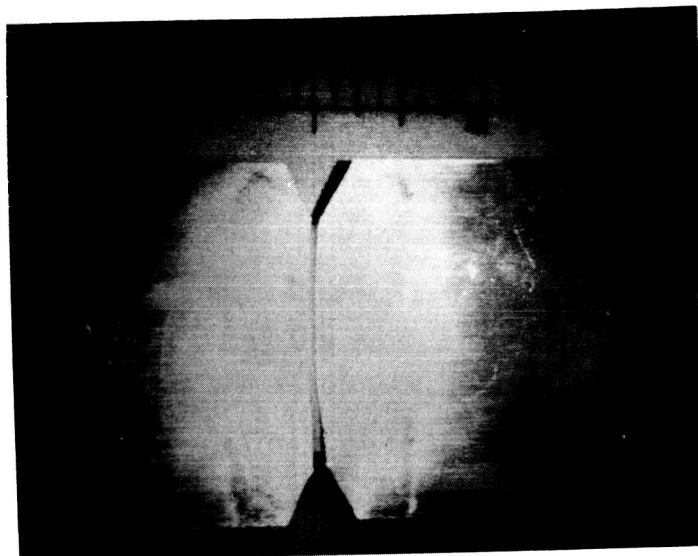
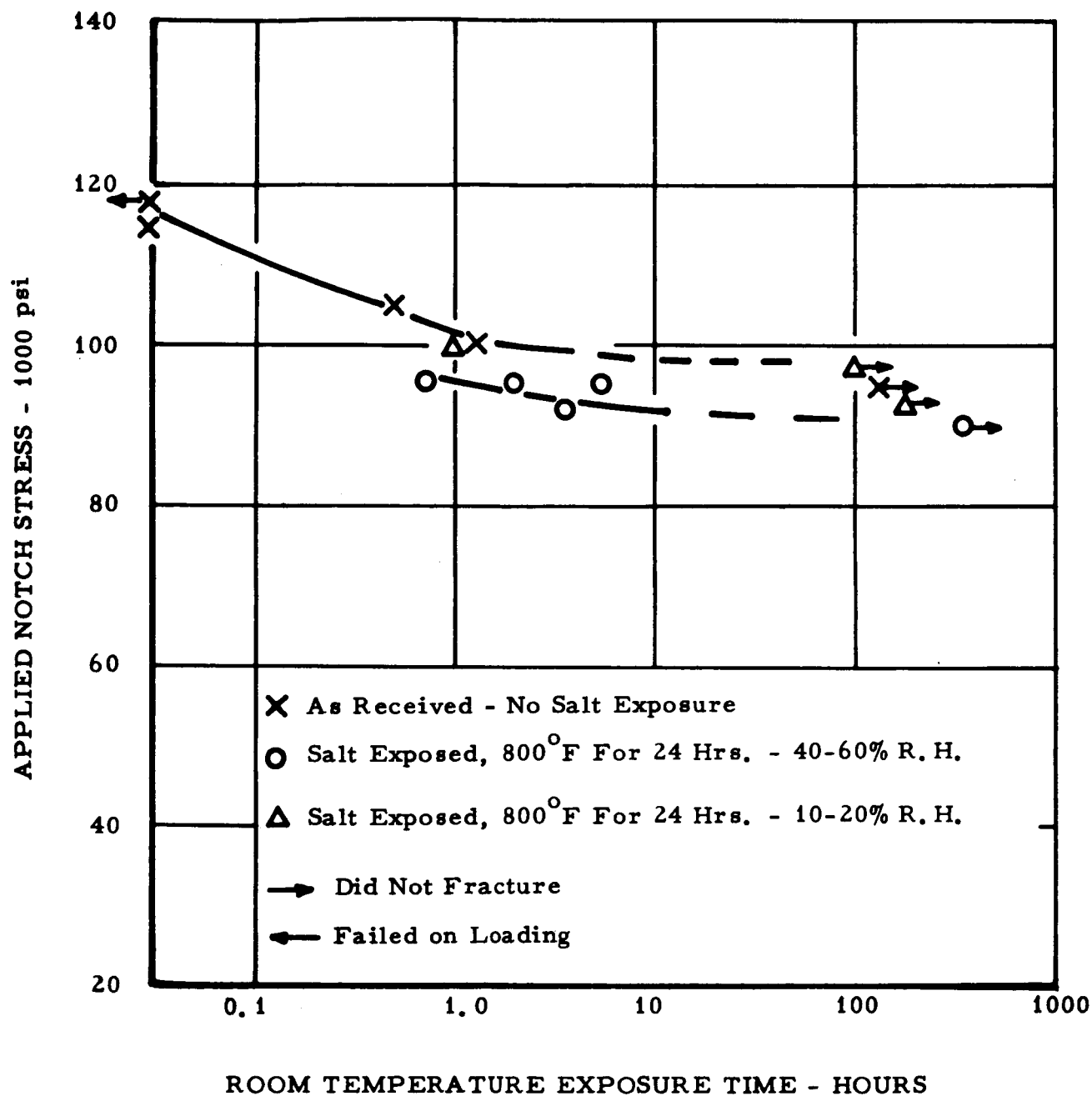


Fig. 10 LOCATION OF FAILURE AND SURFACE APPEARANCE  
OF Ti-8Al-1Mo-1V NOTCH SPECIMEN (1.75 X) TREATED  
AS FOLLOWS:

- (1) Salt coated as shown in Fig. 9
- (2) Exposed 24 hours at 800°F - no load
- (3) Air cooled and washed
- (4) Metallographically polished in vicinity of notch
- (5) Exposed to 100,000 psi at room temperature -  
cracked in <1 minute.



**Fig. 11 THE EFFECT OF AMBIENT HUMIDITY DURING HOT SALT EXPOSURE ON SUBSEQUENT ROOM TEMPERATURE DELAYED FRACTURE OF Ti-8Al-1Mo-1V.**

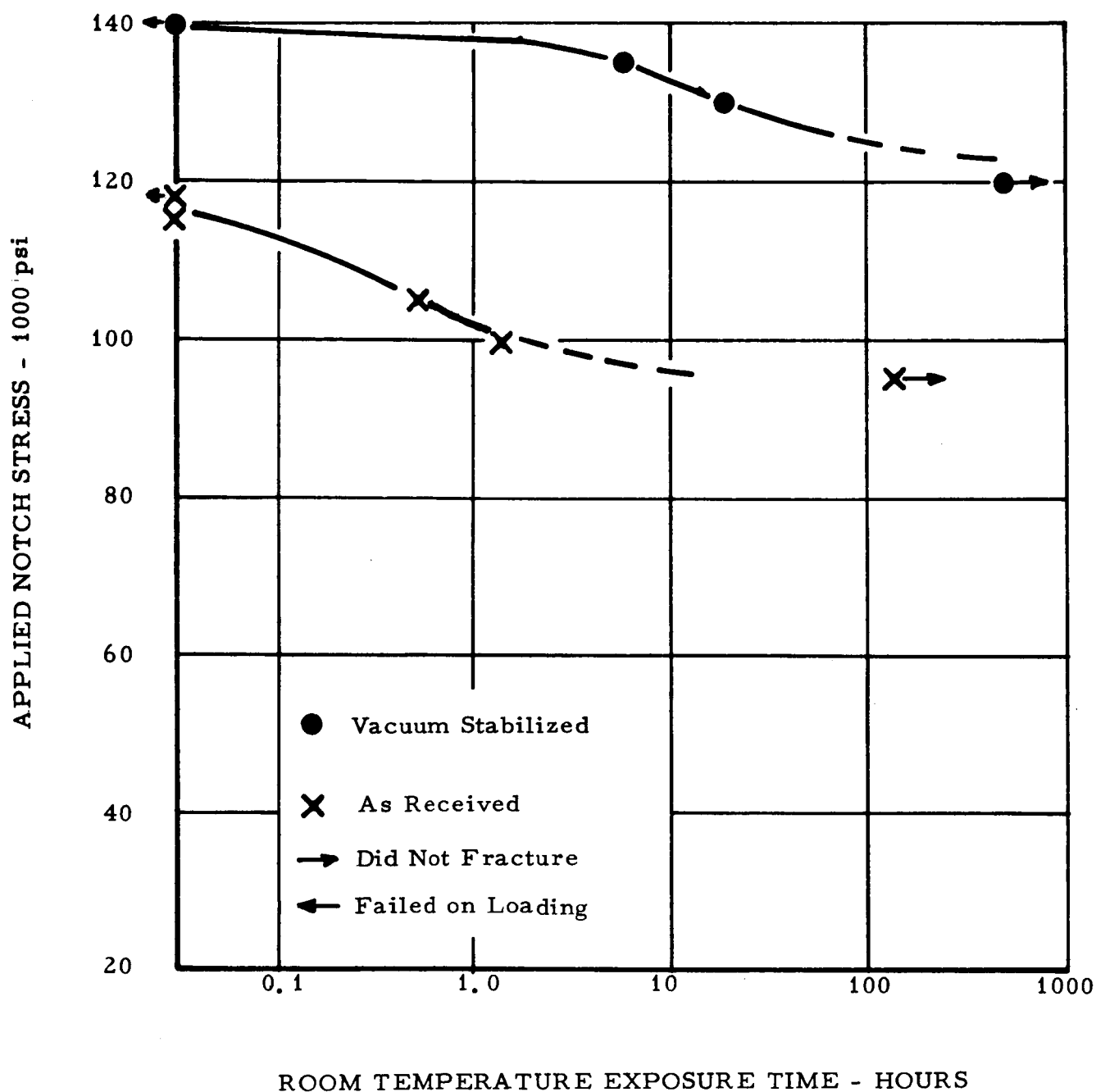


Fig. 12 THE EFFECT OF VACUUM ANNEALING ON ROOM TEMPERATURE DELAYED FRACTURE OF Ti-8Al-1Mo-1V.

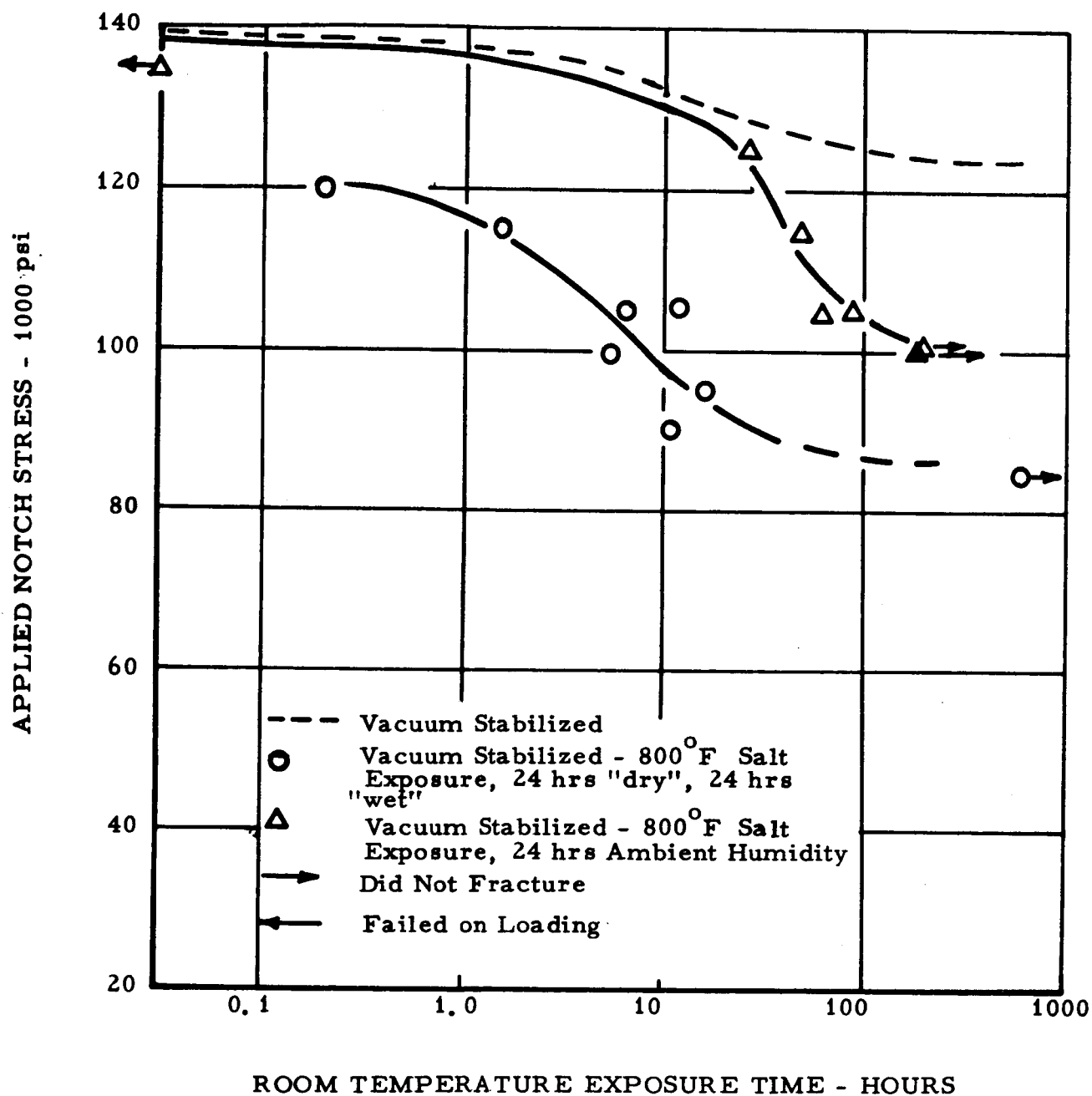


Fig. 13 THE EFFECT OF WATER VAPOR DURING HOT SALT EXPOSURE ON SUBSEQUENT ROOM TEMPERATURE DELAYED FRACTURE OF Ti-8Al-1Mo-1V.

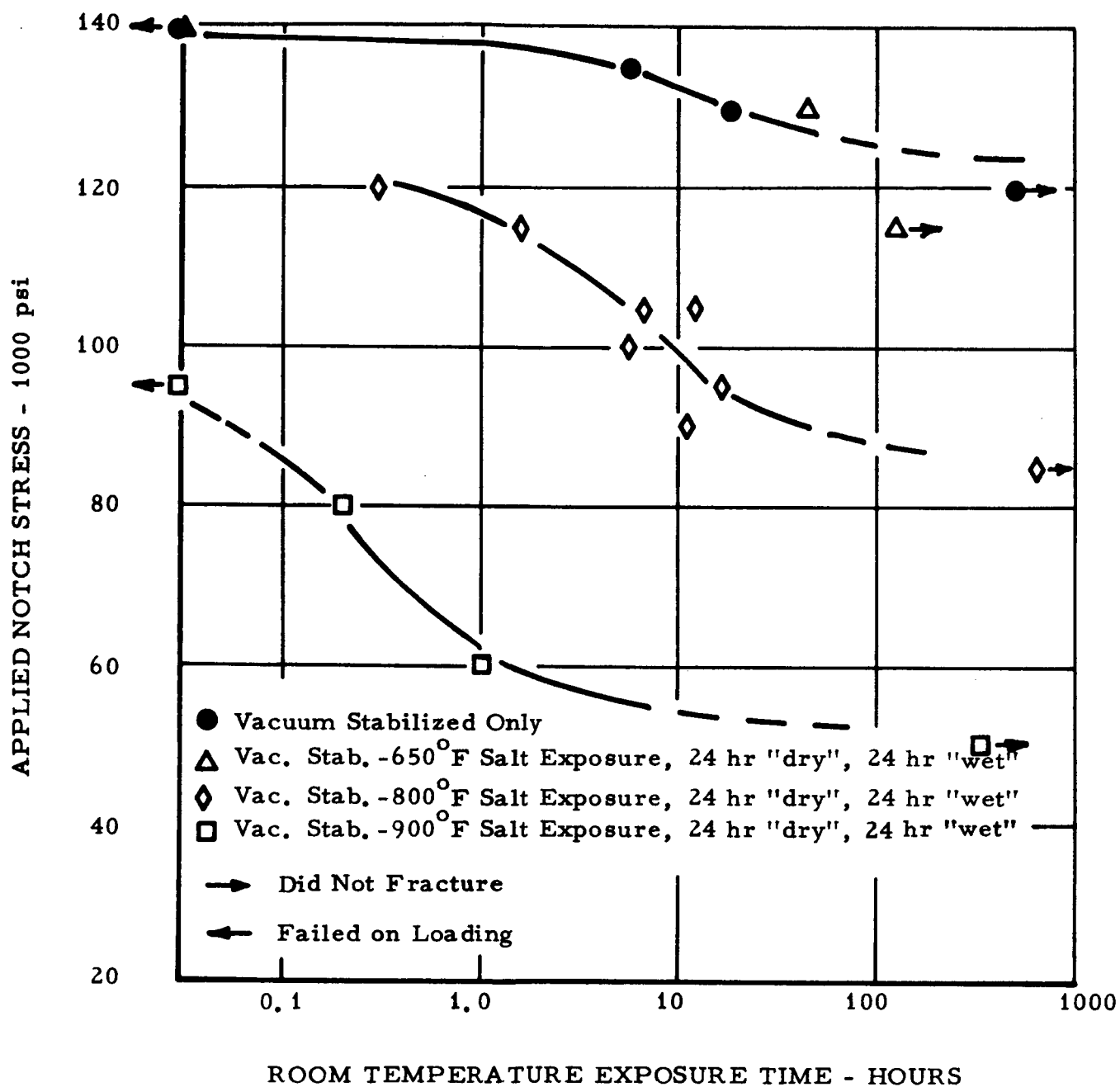


Fig. 14 THE EFFECT OF SALT EXPOSURE TEMPERATURES ON THE SUBSEQUENT ROOM TEMPERATURE DELAYED FRACTURE OF Ti-8Al-1Mo-1V.

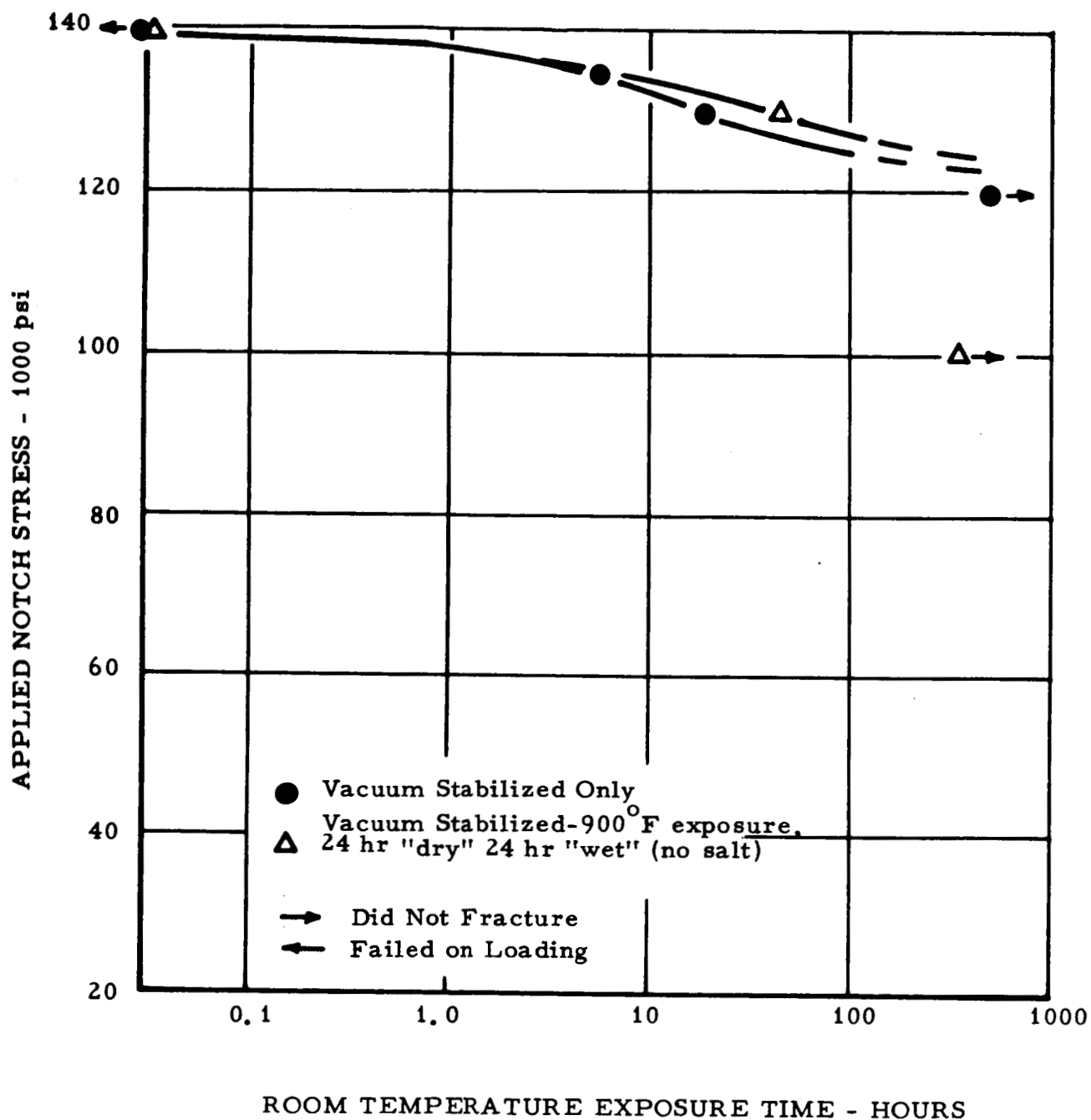


Fig. 15 THE EFFECT OF WATER VAPOR ALONE ON THE SUBSEQUENT ROOM TEMPERATURE DELAYED FRACTURE OF Ti-8Al-1Mo-1V.

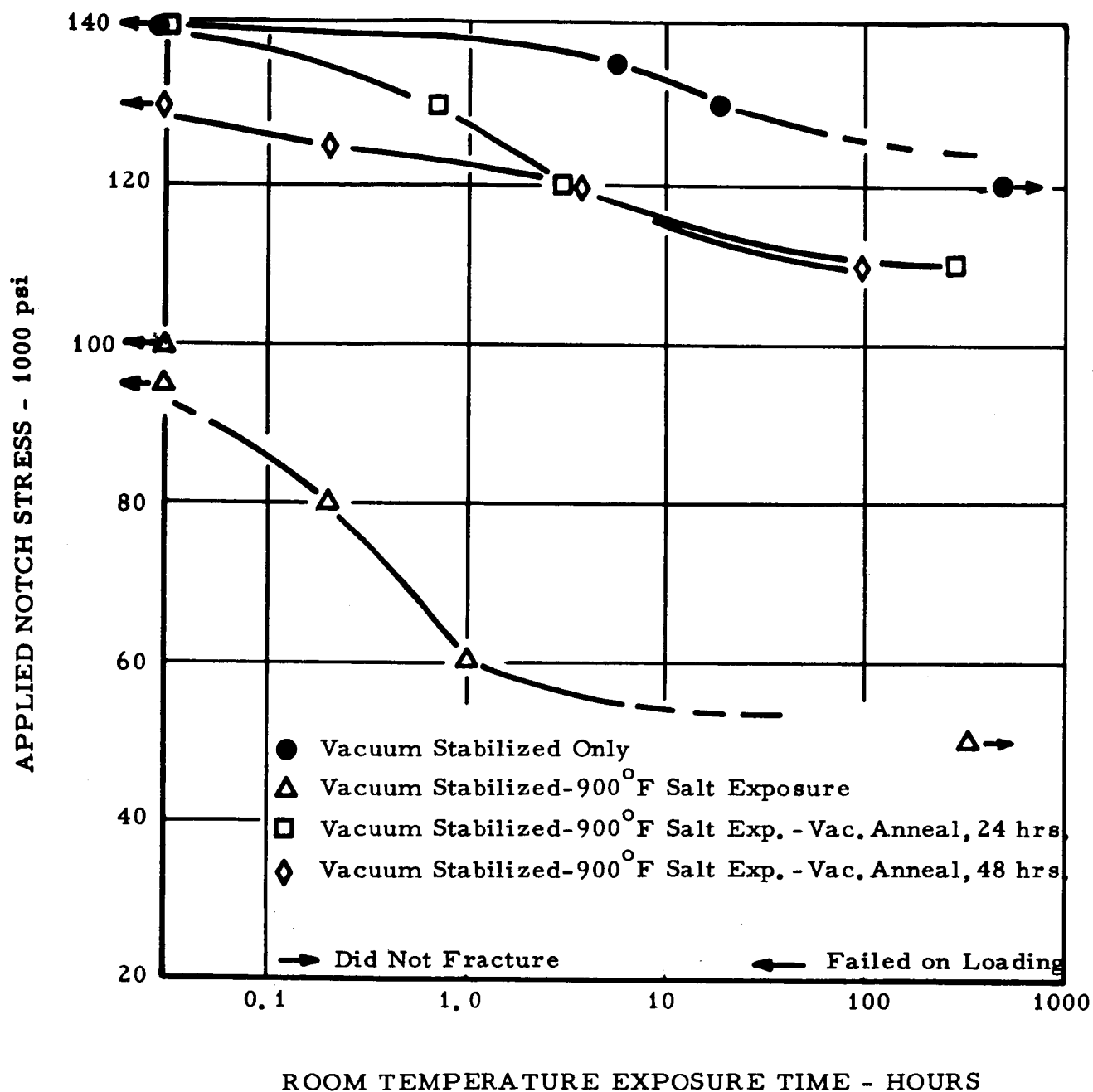


Fig. 16 THE EFFECT OF VACUUM ANNEALING AFTER SALT EXPOSURE ON THE SUBSEQUENT ROOM TEMPERATURE DELAYED FRACTURE OF Ti-8Al-1Mo-1V.